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RESEARCH MEMORANDUM

EFFECTS OF A J34 TURBOJET ENGINE ON SUPERSONIC
DIFFUSER PERFORMANCE

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EFFECTS OF A J34 TURBOJET ENGINE ON SUPERSONIC

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SUMMARY

A translating cone inlet with a variable bypass was investigated at Mach numbers of 1.6, 1.8, and 2.0 when operating with both a choked exit plug and with a J34 turbojet engine. A comparison of inlet performance with the plug and with the engine showed that the most important difference was increased inlet subcritical stability with the engine. Total-pressure recovery and diffuser-exit profiles were essentially unchanged. As buzz started, the total-pressure amplitude at the compressor face station and its rate of change with diffuser air-flow ratio were about the same with the engine as with the plug, but the frequency with the engine was as much as twice that with the plug.

INTRODUCTION

In determining supersonic-diffuser performance in wind-tunnel tests, air flow is ordinarily controlled with a choked exit plug. In reference 1, inlet performance obtained in such a manner is compared with that for the same inlet when operating with an actual engine. The results show that the subcritical stability of this particular inlet was greater with the engine than with the plug. Therefore, it appears that the inlet performance normally reported may not be exactly that which would be obtained with an engine in flight.

The tests of reference 1 were of necessity preliminary in nature and no attempt was made to determine detailed effects of the engine on the inlet. Because it was shown that the effect of an engine may be important, the scope of the program was increased. The Mach number range investigated was extended and detailed effects of spike translation and bypass operation were determined. Refinements were also made in instrumentation, especially in transient-pressure pickups. Results of this expanded investigation in the Lewis 8- by 6-foot supersonic wind tunnel of the effect of a turbojet engine on the performance of a supersonic inlet are presented and discussed in this report. An analysis of the engine performance and the effect of the inlet on the engine is reported in reference 2.

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SYMBOLS

The following symbols are used in this report:

- M Mach number
- P total pressure
- R over-all radial distance from hub to case at station 3
- r radial distance from hub at station 3
- w mass flow
- θ_l cowl-lip-position parameter defined as angle between axis of spike
 and line joining cone apex and cowl lip
- θ_s conical shock angle

Subscripts:

- b station at bypass control door
- 0 conditions of free stream in maximum-capture area of inlet
- 2 station upstream of bypass slots
- 3 compressor face station

Superscript:

- ' local pressure

APPARATUS AND PROCEDURE

A sketch of the nacelle showing the plug and the engine installations with the diffuser is given in figure 1. Although the J34 engine has a comparatively conservative design and was not intended for supersonic flight, it was used for these tests because it was readily available and small enough to avoid tunnel blockage.

The angle θ_l could be varied from 53.6° to 38.4° by translating the forward section of the centerbody without internal contraction at any

position. The four spike positions that were investigated in detail, $\theta_1 = 51^\circ, 46^\circ, 42.6^\circ$, and 38.4° , correspond to positions where the oblique shock would intersect the lip at Mach numbers 1.6, 1.8, 2.0, and 2.4, respectively. The flow-area variations through the diffuser for these spike positions are shown in figure 2.

Inlet-engine matching could be controlled either with the translating spike or a bypass. Engine bypass air was bled through slots in the subsonic diffuser wall into the cavity between the diffuser wall and the nacelle skin. From there the air was returned to the free stream through a hinged door in the nacelle skin.

Air flow through the engine was computed from the nozzle total pressure, temperature, and sonic area, minus the fuel flow. The mass flow at the exit of the diffuser for the cold tests was determined from the plug sonic area and the static pressure and area just upstream of the plug. Bypass air flow was computed from the sonic discharge area and total pressure.

DISCUSSION OF RESULTS

Basic Diffuser Performance

The pressure-recovery - air-flow curves of the diffuser when operating with the plug and with the engine while the bypass was closed are presented in figures 3(a) to (d). For some spike positions where buzz occurred, the inlet became stable again when the mass-flow ratio had been reduced to lower values. (The stability limits in these cases will be referred to as the upper and lower stability limits.) Stability at the high Mach numbers was best with the oblique shock within the cowl (high values of θ_1), but the recovery was low. The inlet was more stable with the engine than with the plug. The critical recovery of this inlet with the oblique shock at or upstream of the cowl lip was good. At a free-stream Mach number of 2.0, for example, the losses were only 4 percent greater than the theoretical shock losses. The pressure recovery was essentially the same with the plug as with the engine except where the stability had changed.

For the data of figures 3(e) to (h), the bypass door was opened a constant amount. Because the air flow presented is that downstream of the bypass system (compressor-inlet station) and since bypass air flow varies directly with diffuser recovery, the supercritical mass flow is not constant. Again, as with the bypass closed, stability was greater with the engine than with the plug. Recovery was the same with the engine as with the plug except where stability had changed.

The curves of figure 4 indicate the air flow spilled by the bypass. The scatter of data at a given Mach number is probably due to changes in profiles at the bypass slots. An analysis of data in figures 3 and 4 indicates that opening the bypass resulted in little measureable change in inlet pressure recovery for comparable capture mass-flow ratios and normal-shock positions.

The total pressure of the air at the bypass exit is of interest since it is an indication of the drag associated with this method of inlet-engine matching. This total pressure was not only dependent upon the average pressure recovery of the inlet but was also sensitive to the velocity profiles in the diffuser because the bypass slots were located in the outer subsonic diffuser wall. These profiles varied as the oblique-shock position relative to the cowl lip was varied. For this inlet, the measured total pressure at the bypass exit varied from 68 to 78 percent of the diffuser discharge total pressure at critical operation as θ_l was varied from 51° to 38.4° , respectively, and gradually increased for all θ_l 's to about 80 percent as the inlet flow became subcritical.

Inlet Stability

The inlet-stability limits with the bypass closed are shown in figure 5. The variations of supercritical mass-flow ratio with θ_l and $\theta_l = \theta_s$ for the different Mach numbers are also indicated on the figure. The influence of the engine on the inlet was to increase the region of stability. Although there was inlet buzz at a Mach number of 1.6 with the plug configuration at mass-flow ratios less than 0.6, the inlet was stable with the engine to mass-flow ratios of 0.4 (the minimum air flow investigated).

Although the cause of buzz could not be determined in all cases, schlieren photographs indicated that at Mach numbers of 1.6 and 1.8 buzz occurred with the vortex sheet near the cowl inner surface (ref. 3). At Mach 2.0 cone surface boundary-layer separation was quite extensive (as would be expected from ref. 4) and it, rather than the vortex sheet, may have been the cause of buzz in some cases. In particular, with $\theta_l < \theta_s$ the vortex sheet was still outside the cowl at the upper stability limit.

The change in stability limits with the plug configuration caused by opening the bypass is shown in figures 6(a) to (c). Opening the bypass destabilized the inlet for all Mach numbers in the range investigated. At Mach numbers of 1.8 and 2.0 the upper stability limits were essentially unchanged, but at a Mach number of 1.6 this limit was extended to considerably greater θ_l 's. The lower stability limit was appreciably less at all Mach numbers.

The comparison between stability limits for the engine configuration with the bypass opened and closed is given in figures 6(d) to (f). The destabilizing effect of the bypass is again apparent; however, the magnitude of the effect is considerably less with the engine than with the plug configuration. At a Mach number of 1.6, buzz did not occur over the range of mass-flow ratio investigated (to 0.6 and 0.4 with the bypass opened and closed, respectively), and at Mach 1.8, the narrow region of buzz extended over a larger range of θ_l with the bypass opened than closed. The destabilizing effect was small at Mach 2.0.

Buzz Amplitude and Frequency

The total-pressure amplitude and the frequency of buzz at the compressor face station are presented in figure 7 for both configurations. Additional amplitudes at other stations through the inlet and engine are given in reference 2. Static-pressure amplitudes varied with air flow in about the same manner as shown for the total pressures.

Although buzz started at higher capture mass-flow ratios with the plug than with the engine, the amplitudes near the start of buzz were about the same and increased with decreasing air flow at approximately the same rate. Opening the bypass had little effect on buzz amplitude except where stability limits had changed appreciably.

With the engine, the frequency at the start of buzz was as much as twice that with the plug. Opening the bypass while operating with the plug increased the buzz frequency, but with the engine the frequency change was negligible.

Diffuser-Exit Profiles

A sampling of the pressure recovery profiles at the diffuser exit is shown in figure 8. The profiles in figure 8(a) were obtained with the plug while the bypass was opened and the spike was positioned for $\theta_l = \theta_s$. With this particular design of the bypass, the profiles were not quite symmetrical. The operating conditions of the inlet were selected so that these profiles can be compared with those for similar inlet conditions during operation with the engine. For the profiles with the engine (fig. 8(b)), the bypass again was opened and $\theta_l = \theta_s$. The inlet mass-flow ratio (which was dependent upon engine speed) was as close to critical operation as possible without exceeding rated engine speed. In general these profiles were similar to those with the plug. At this particular survey diameter, however, they were slightly more nonsymmetrical than with the plug.

For the profiles in figure 8(c), the bypass was closed and again the inlet was as close to critical as possible without exceeding rated engine speed. With the bypass closed the profiles at similar inlet operating conditions were identical for the plug and for the engine, and therefore the data for the plug are not presented. As the supersonic Mach number increased, the region of high total pressure shifted outward from the hub as it did with the bypass open. At a free-stream Mach number of 0.12 with the engine near maximum speed, diffuser recovery and air-flow distribution were slightly better with the bypass open than closed. Further improvements probably could be made by redesigning the structure of the bypass air-flow passage.

The change in profile with spike position as critical inlet operation was maintained at a Mach number of 2.0 is shown in figure 8(d). As the spike was extended, the region of high total pressure shifted outward from the hub.

Variations in profiles with normal-shock position for $\theta_l = \theta_s$ at Mach 2.0 are shown in figure 8(e). In changing from supercritical to subcritical operation, the region of high total pressure shifted inward from the compressor casing.

SUMMARY OF RESULTS

A translating spike inlet employing a variable bypass was tested at Mach numbers of 1.6, 1.8, and 2.0, both with a choked exit plug and with a J34 turbojet engine. The results were as follows:

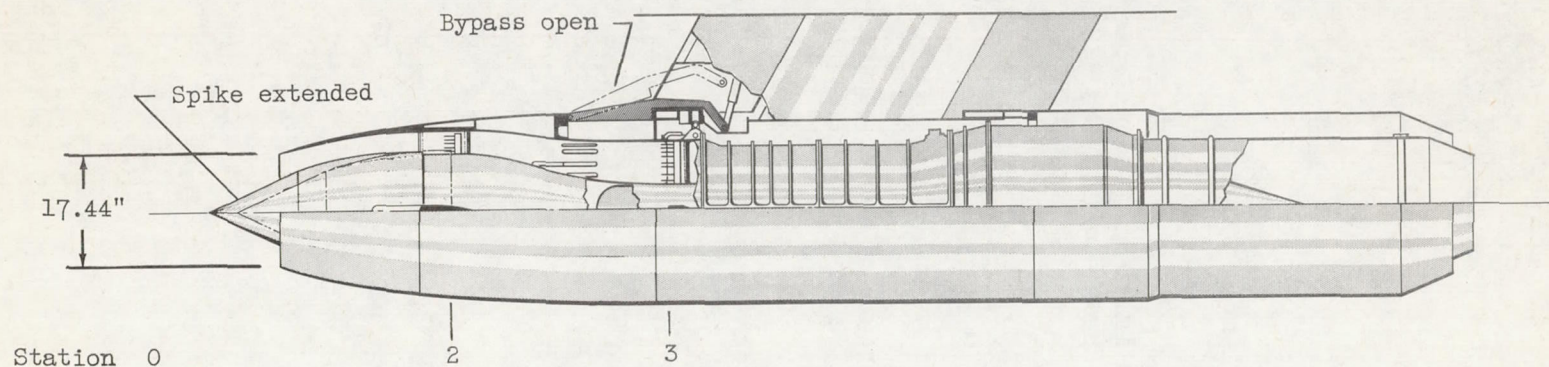
1. Under stable conditions, total-pressure recovery and diffuser-exit profiles were essentially the same with the plug or the engine configuration.
2. Subcritical stability was greater with the engine than with the plug.
3. The stable range of subcritical capture mass-flow ratio was less with the bypass opened than closed, but this decrease was less with the engine than with the plug.
4. Regardless of bypass position, the total-pressure amplitude at the diffuser exit at the start of buzz and its rate of change with mass-flow ratio were about the same with the plug as with the engine.

5. With the engine, frequency at the start of buzz was as much as twice that with the plug. Opening the bypass increased the frequency at the start of buzz by as much as one-half with the plug, but with the engine the change was negligible.

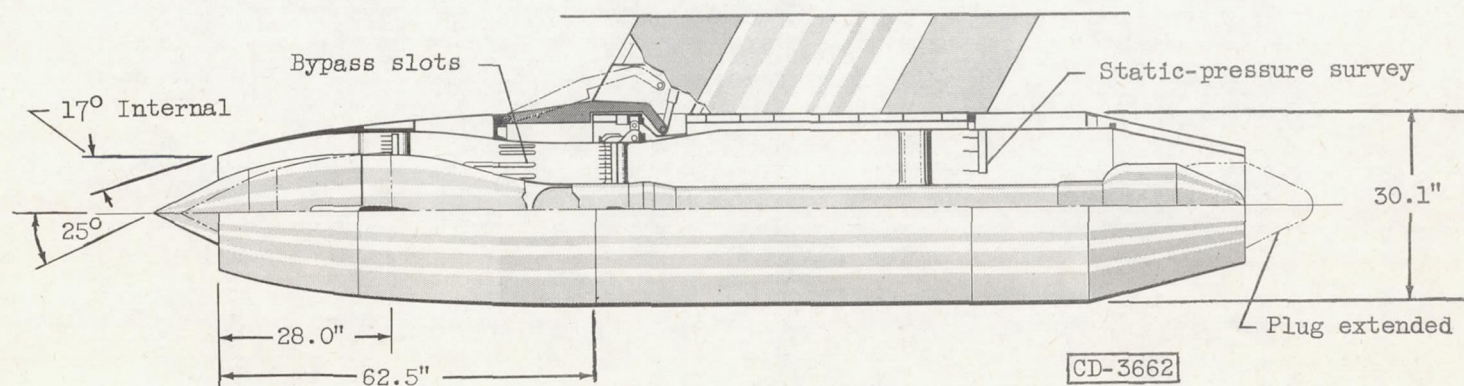
Lewis Flight Propulsion Laboratory
National Advisory Committee for Aeronautics
Cleveland, Ohio, September 22, 1955

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1. Nettles, J. C., and Leissler, L. A.: Investigation of Adjustable Supersonic Inlet in Combination with J34 Engine up to Mach 2.0. NACA RM E54H11, 1954.
2. Beke, A. L., Englert, G. W., and Beheim, M. A.: Effect of an Adjustable Supersonic Inlet on the Performance up to Mach Number of 2.0 of a J34 Turbojet Engine. NACA RM E55I27, 1955.
3. Ferri, Antonio, and Nucci, Louis M.: The Origin of Aerodynamic Instability of Supersonic Inlet at Subcritical Conditions. NACA RM L50K30, 1951.
4. Nussdorfer, T. J.: Some Observations of Shock-Induced Turbulent Separation on Supersonic Diffusers. NACA RM E51L26, 1954.



(a) J34 Turbojet installation.



(b) Exit-plug installation.

Figure 1. - Nacelle configurations.

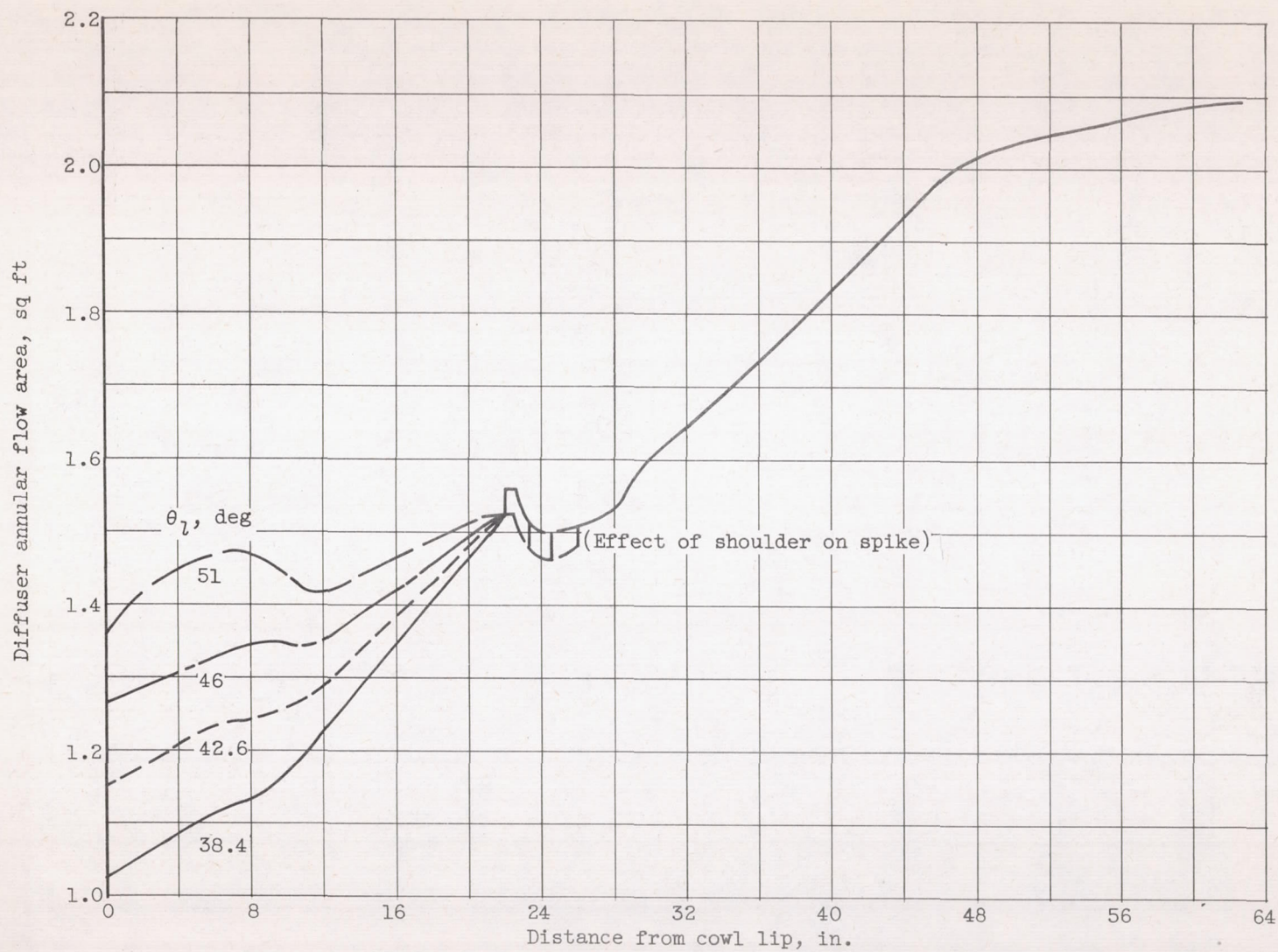
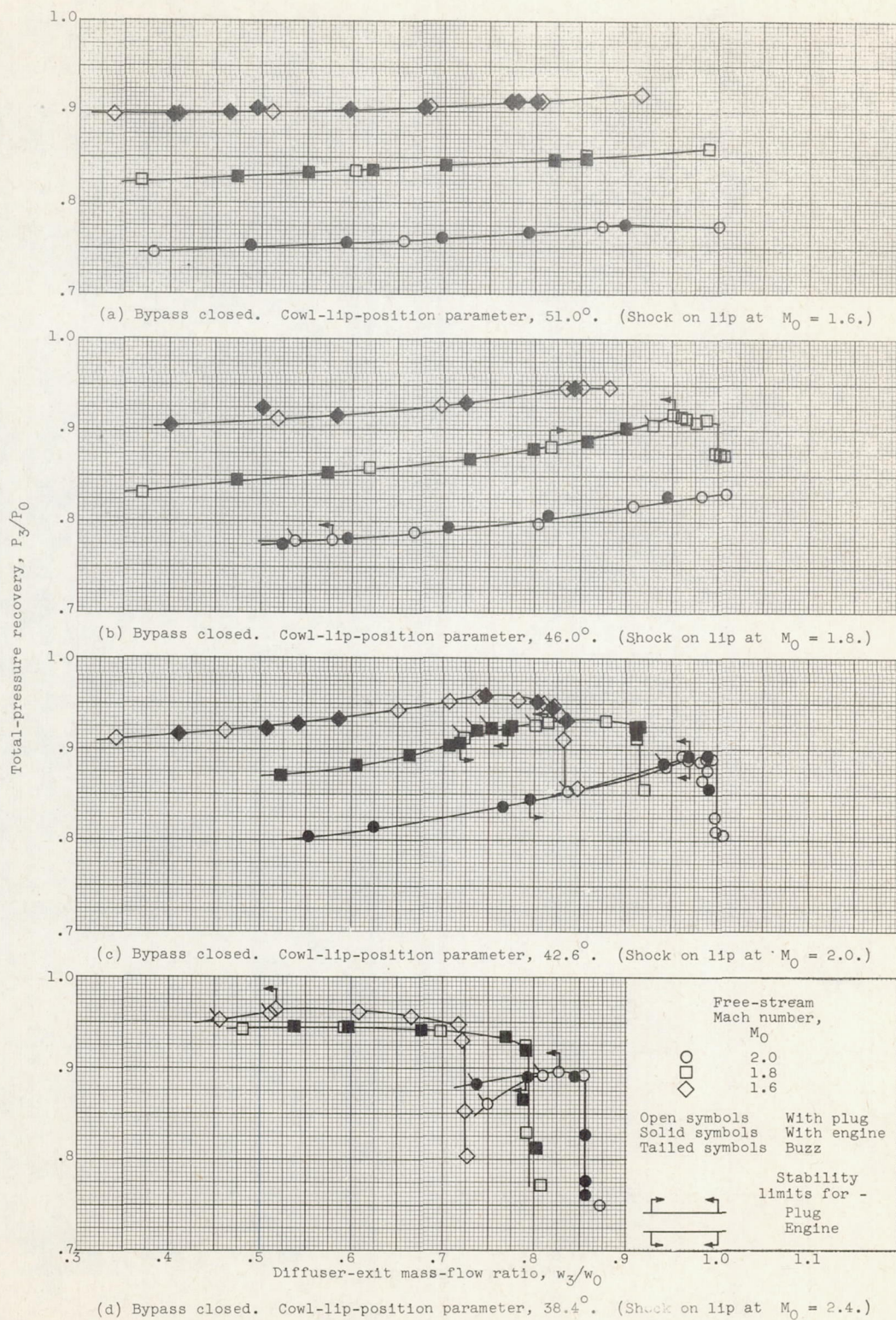
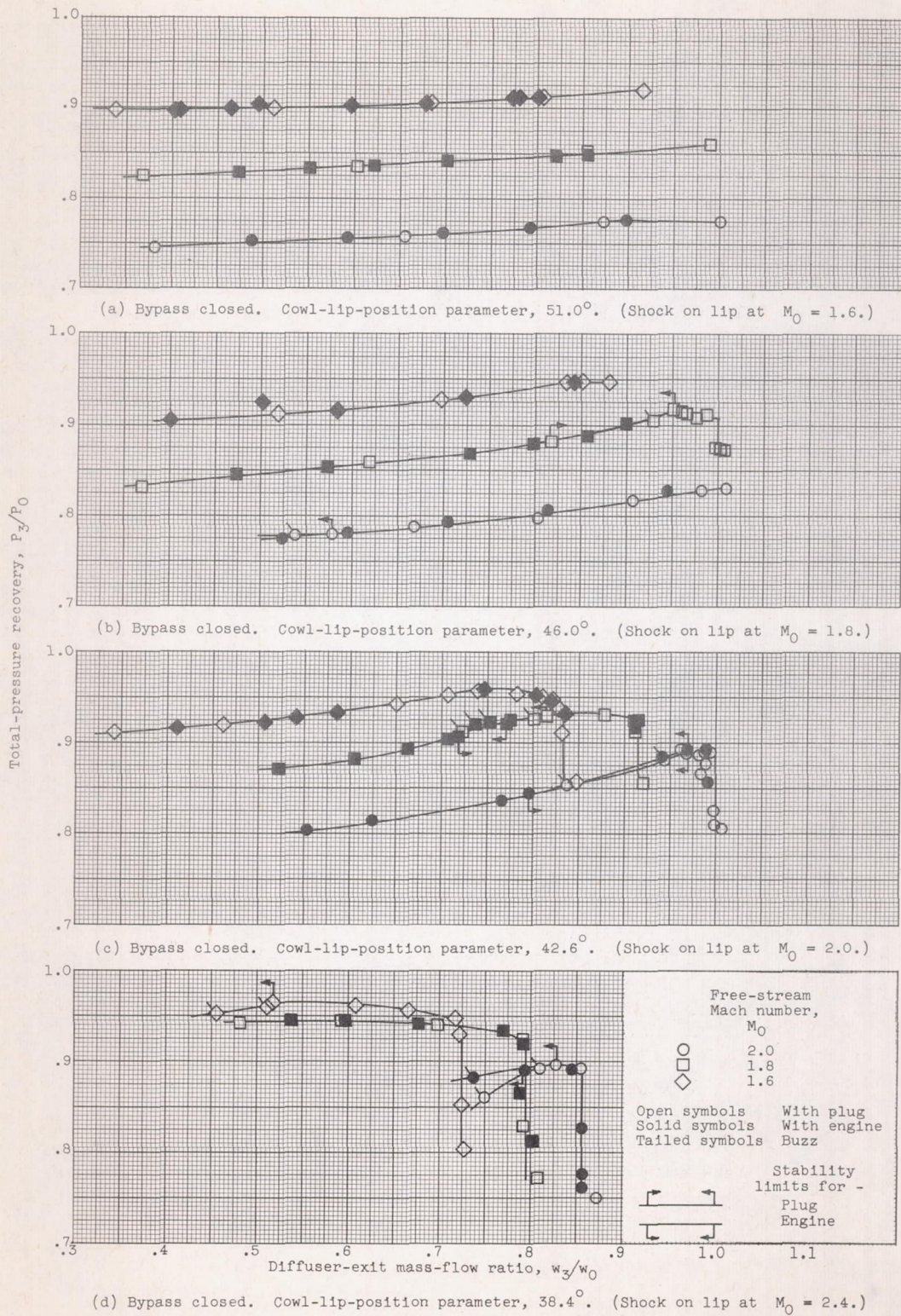


Figure 2. - Diffuser flow-area variations.





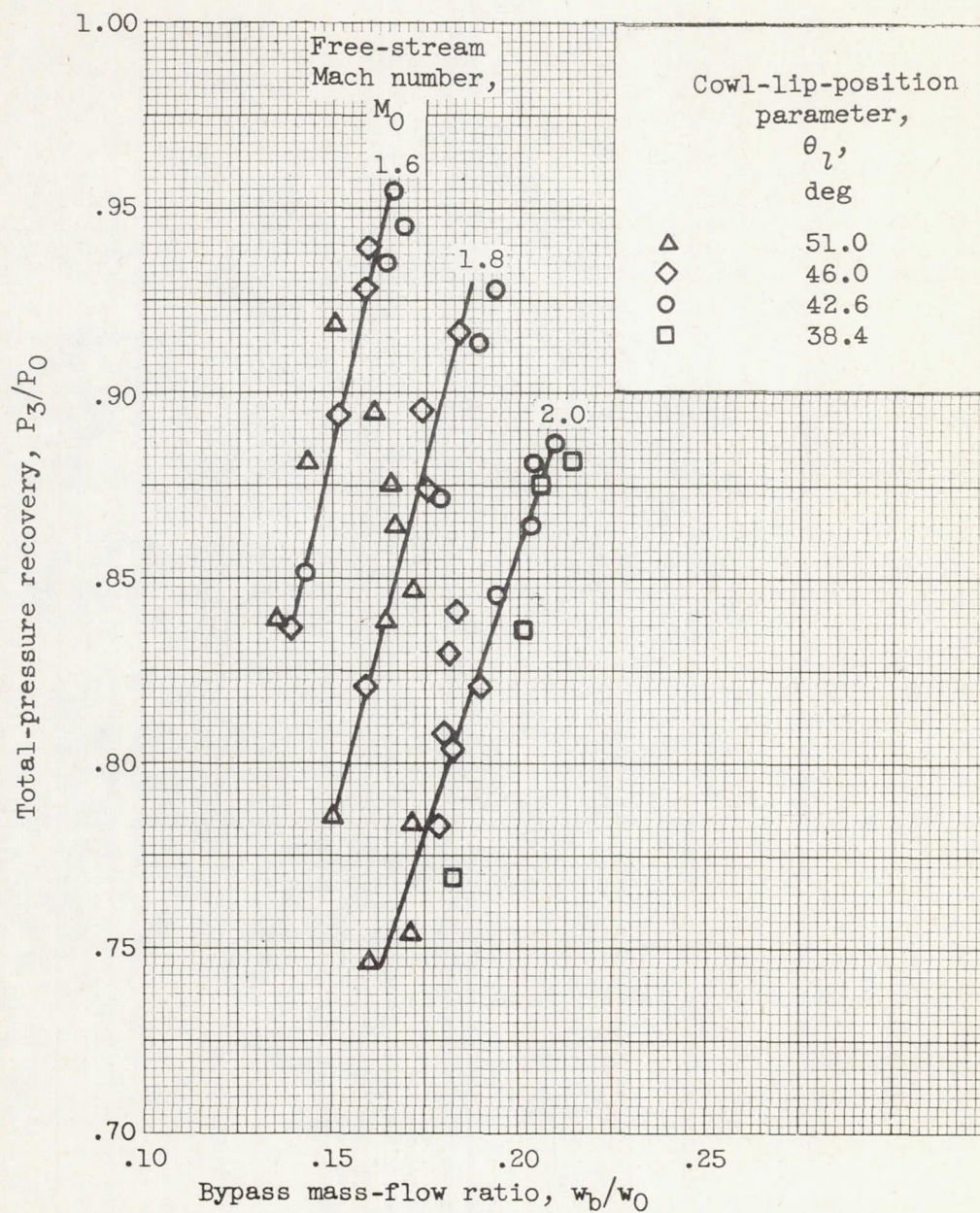


Figure 4. - Variation of bypass air flow with diffuser recovery.

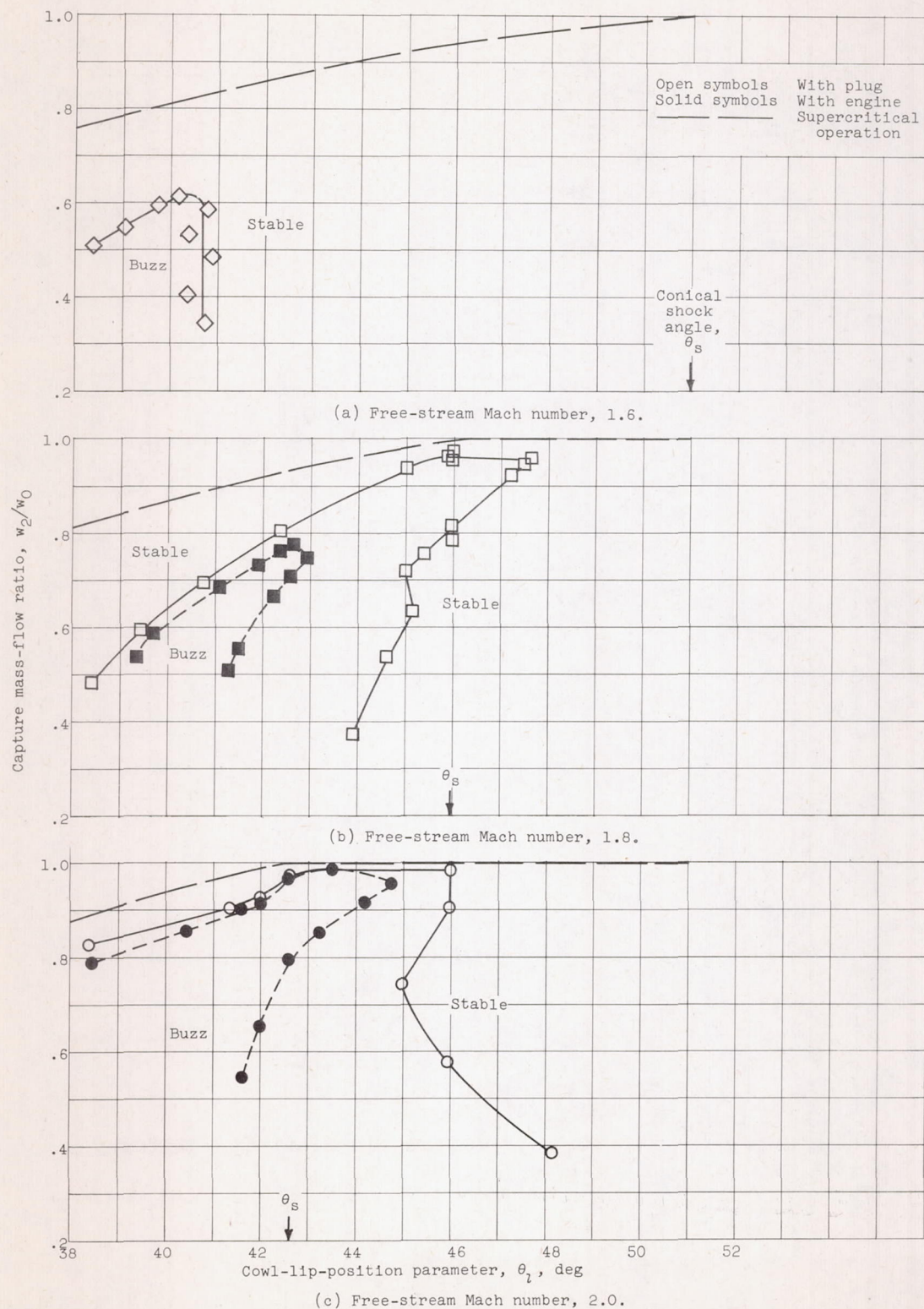


Figure 5. - Inlet subcritical stability with plug and with engine. Bypass closed.

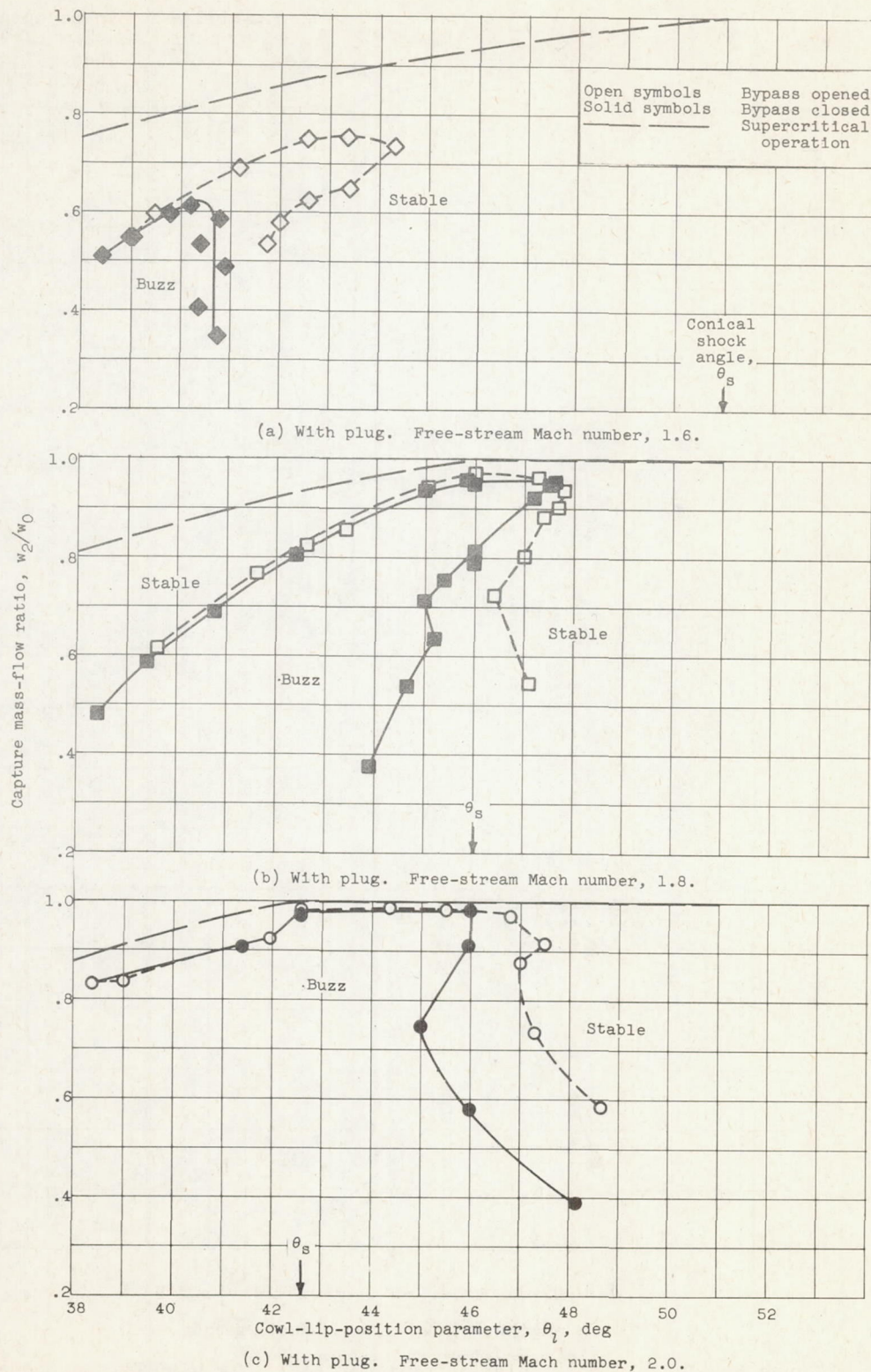
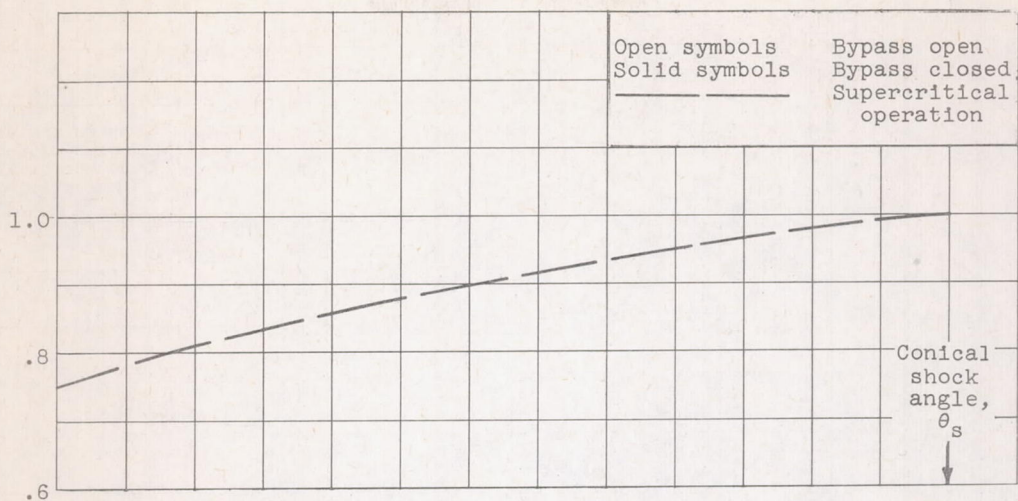
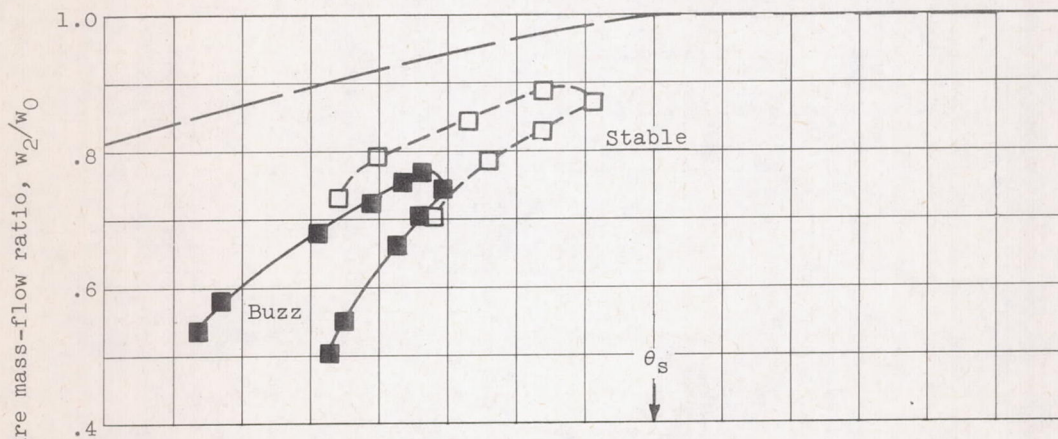


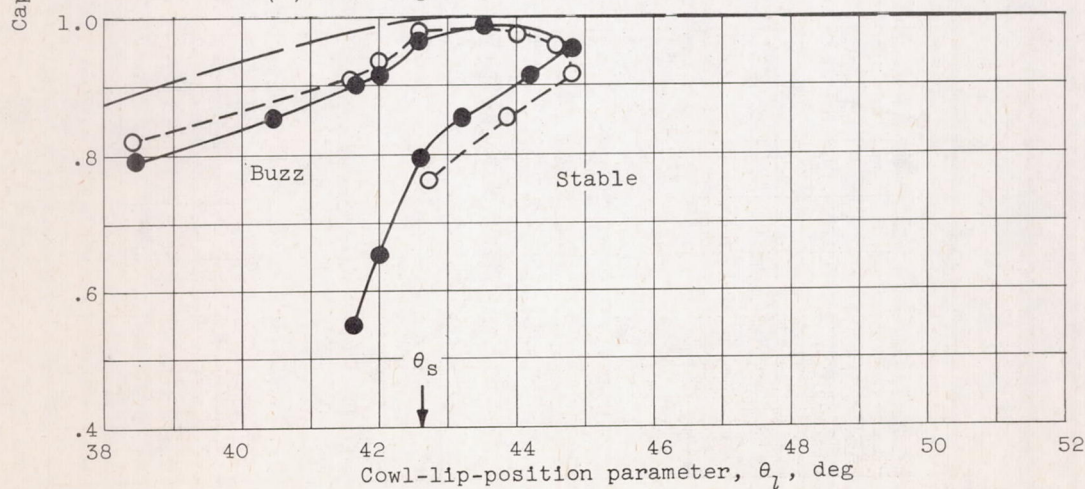
Figure 6. - Inlet subcritical stability with bypass opened and closed.



(d) With engine. Free-stream Mach number, 1.6.



(e) With engine. Free-stream Mach number, 1.8.



(f) With engine. Free-stream Mach number, 2.0.

Figure 6. - Concluded. Inlet subcritical stability with bypass opened and closed.

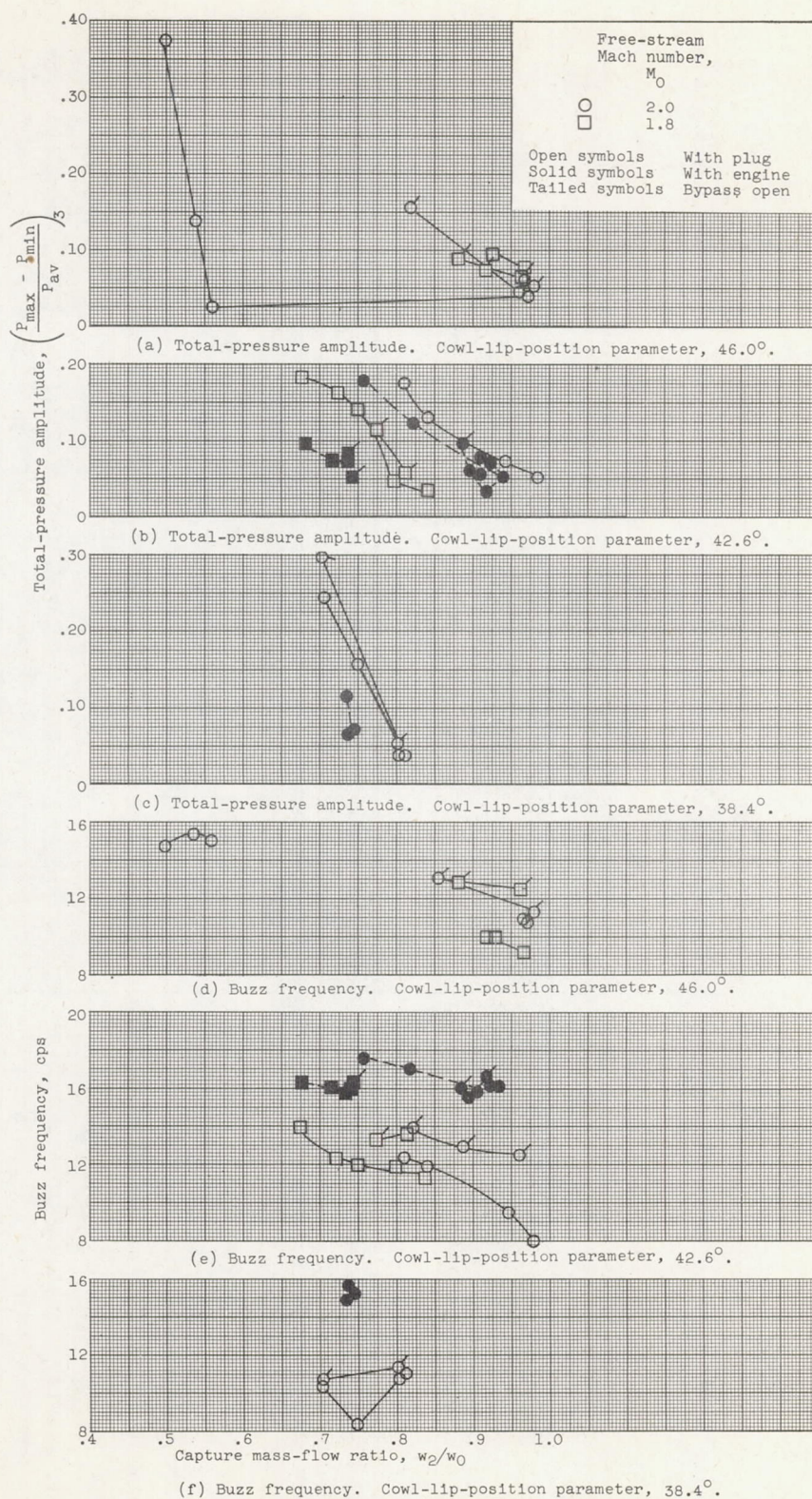


Figure 7. - Buzz characteristics at compressor face station.

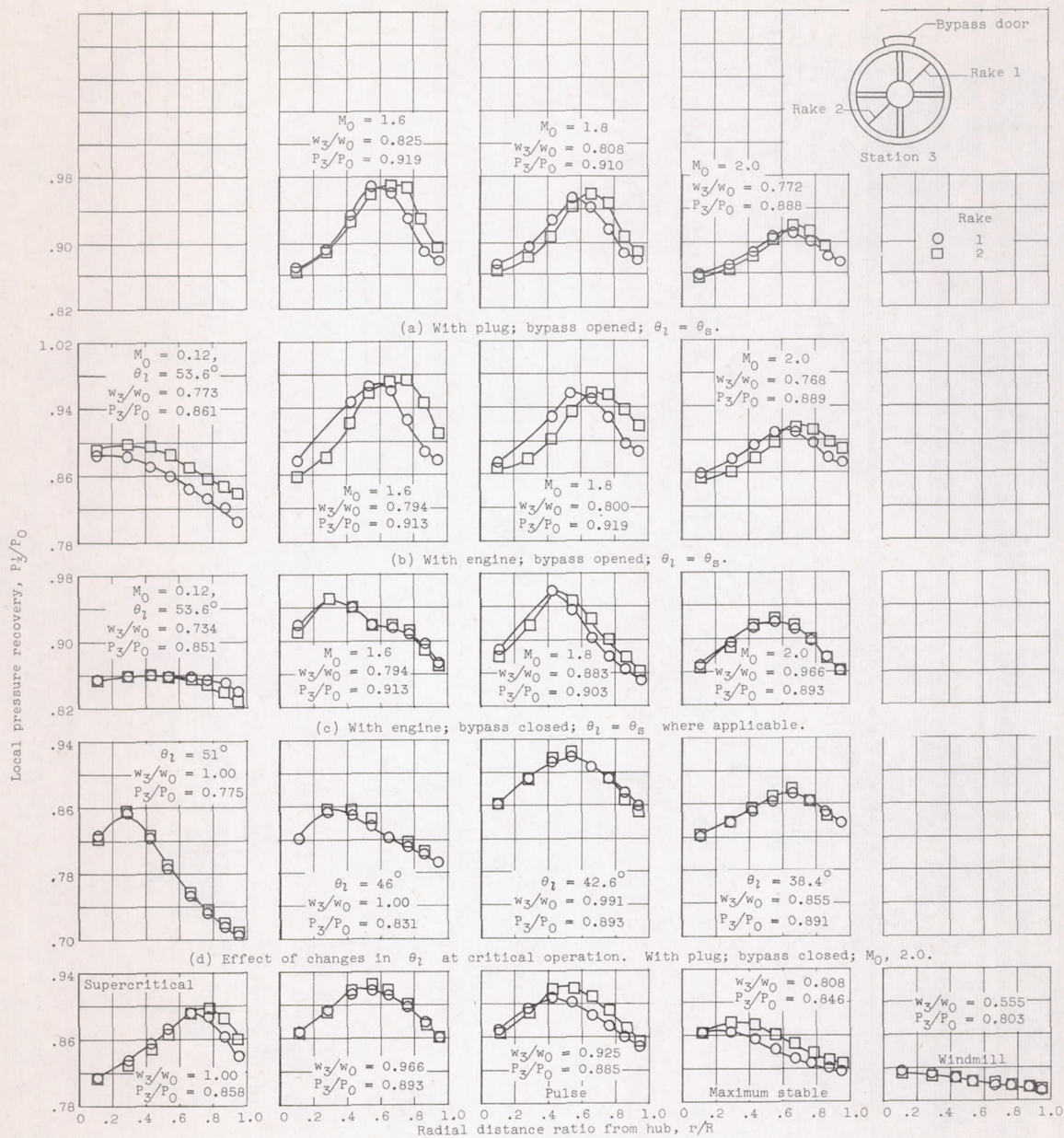


Figure 8. - Diffuser-exit total-pressure recovery profiles. M_0 , free-stream Mach number, w_3/w_0 , diffuser-exit mass-flow ratio; P_2/P_0 , total-pressure recovery; θ_1 , cowl-lip-position parameter.